EUV Light Source – The Path to HVM

Scalability in Practice

Harald Verbraak et al. *(all people at XTREME)*

2011 International Workshop on EUV and Soft X-ray Sources

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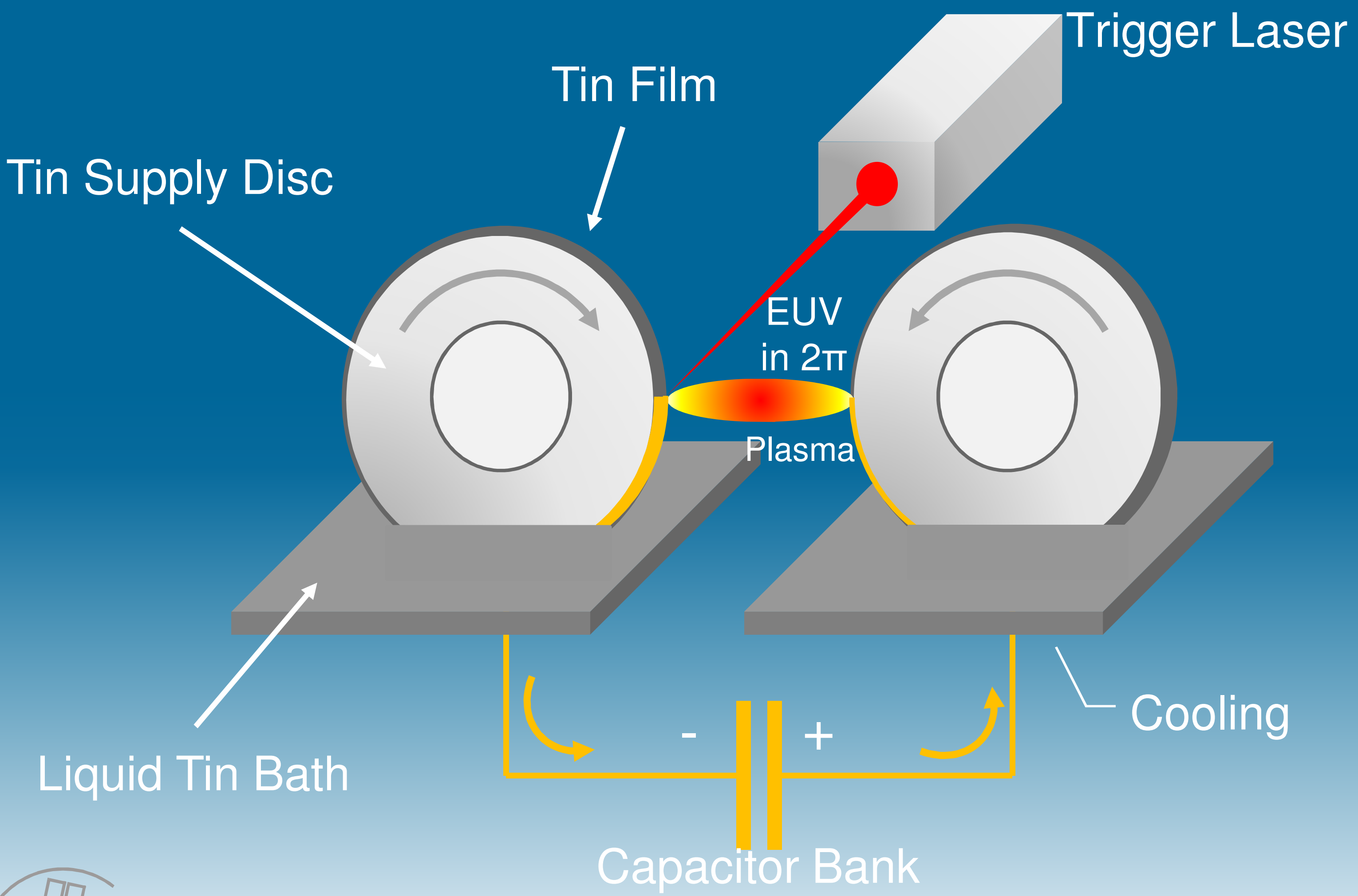
Today's Talk

- LDP Technology – A Quick Refresher
- How to reach high powers of EUV ?
- Where Are We Now ?
- What's Next ?
- Conclusions

LDP* Technology Concept – A Quick Refresher

*Laser assisted Discharge Plasma



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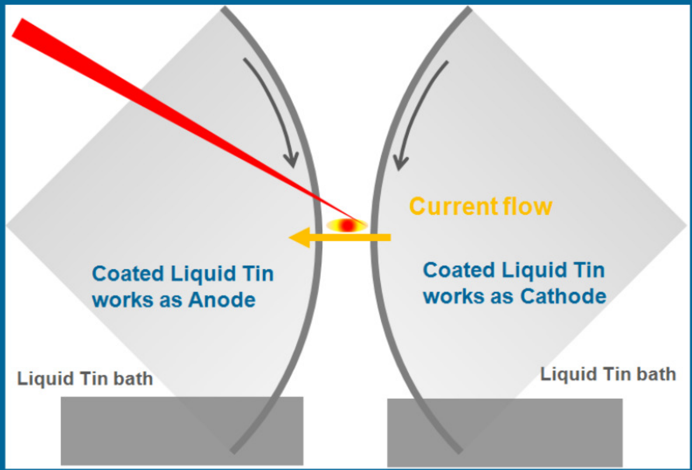
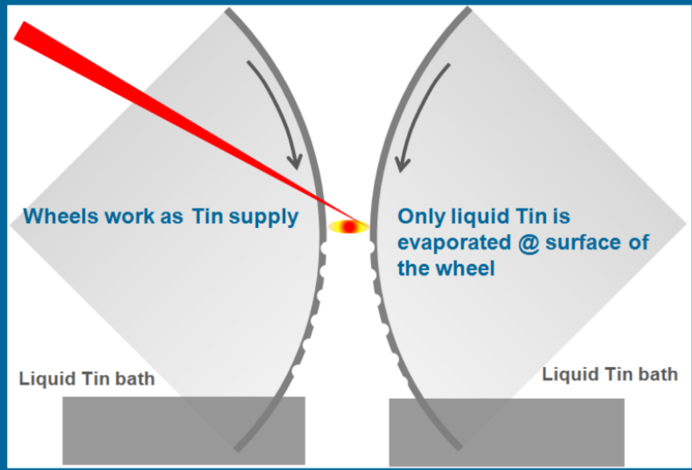
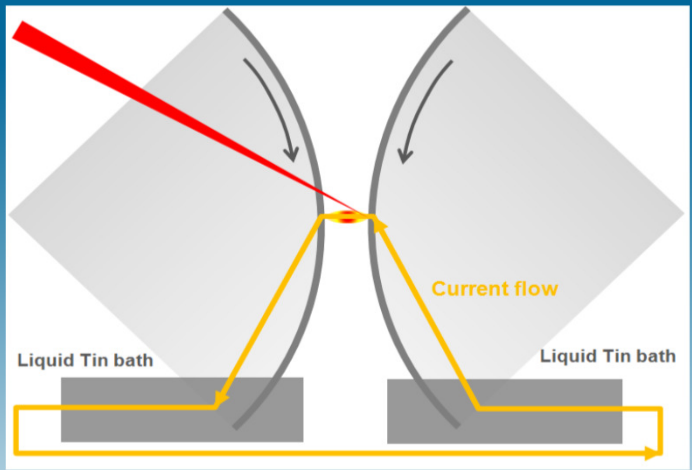
LDP Technology – Tin Fulfills Multiple Roles



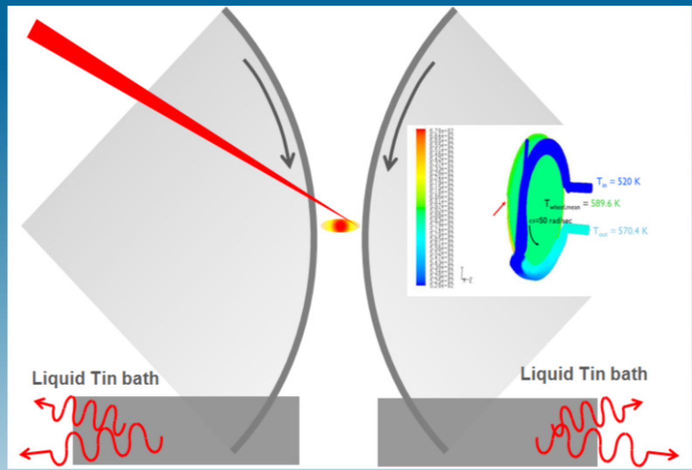
Tin as electrodes



Tin as wheel protection

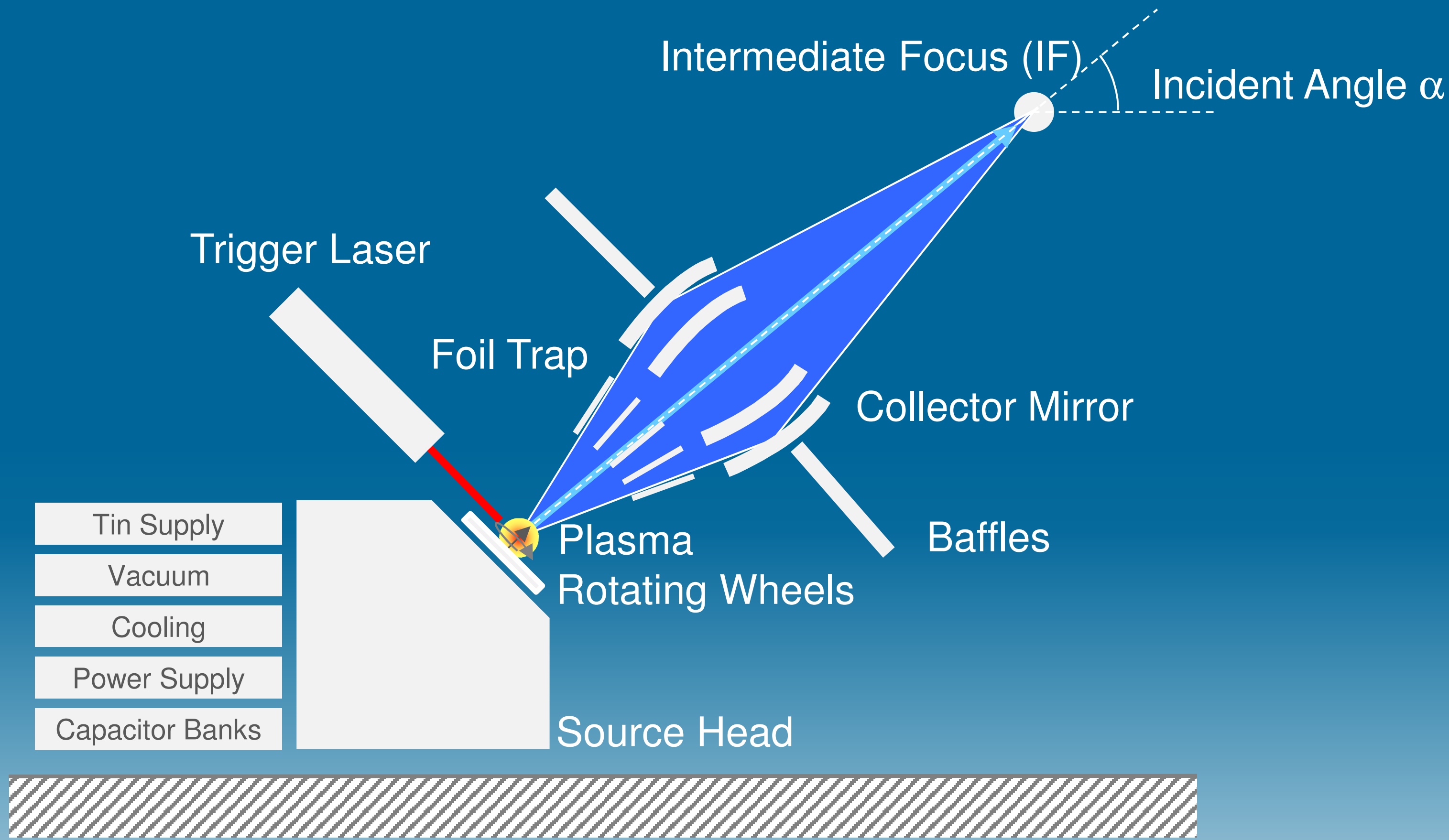


Tin as conductor

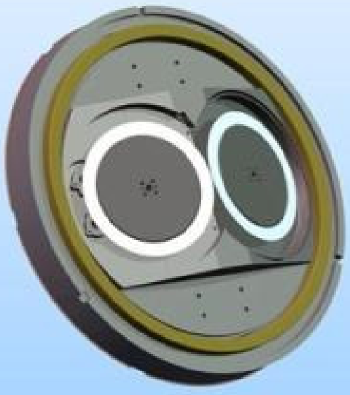


Tin as dynamic coolant

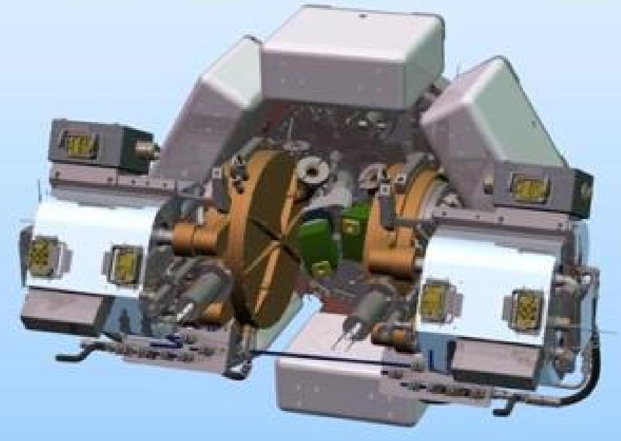
LDP Technology – Producing, Collecting & Directing EUV



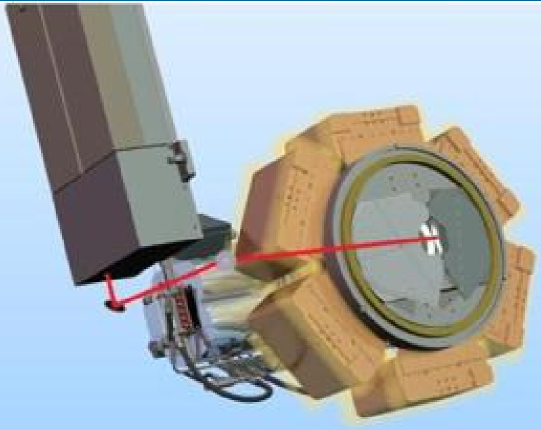
LDP Technology – Modular Architecture



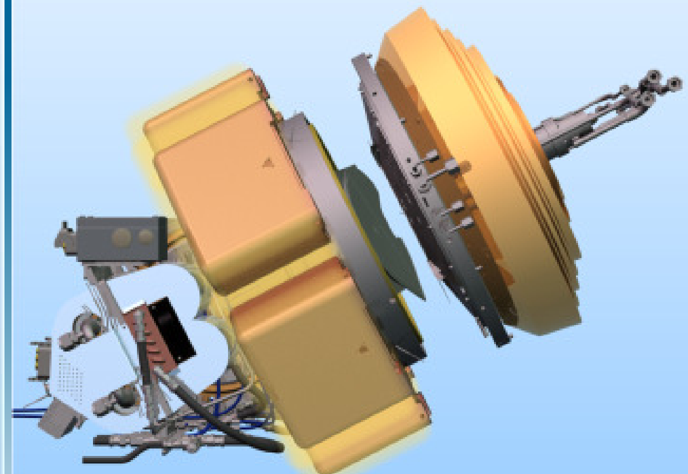
Rotating Wheels



Source Head + Tin Cooling System



Trigger Laser + Capacitor Bank



Foil Trap + Collector Mirror

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Enabling EUV Lithography

EUV SCANNER		EUV Source
Imaging	→	Clean Photon (& Spectral purity)
Yield CD uniformity Iso-Dense Bias	→	Stability (Dose, Timing …)
Maximum Throughput	→	Power
Effective Throughput	→	Duty Cycle

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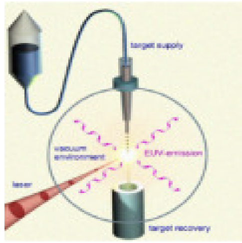
Why LDP - The Best Of Both Worlds

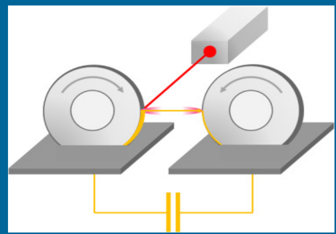
Laser-assisted Discharge Plasma

Traditional LPP



Scalable

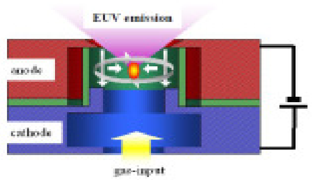
LDP



Stable

Scalable

Traditional DPP



Stable

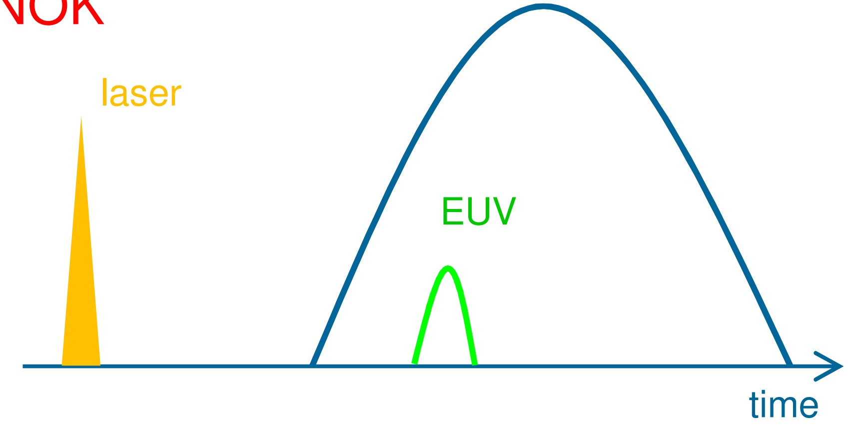
Clean EUV Power

- EUV power produced by the source (CE, input power)
- Collectable EUV power
- Foil Trap Transmission
- Collector Reflectivity
- Spectral Purity Filter (SPF) → LDP photons are clean, no need for SPF

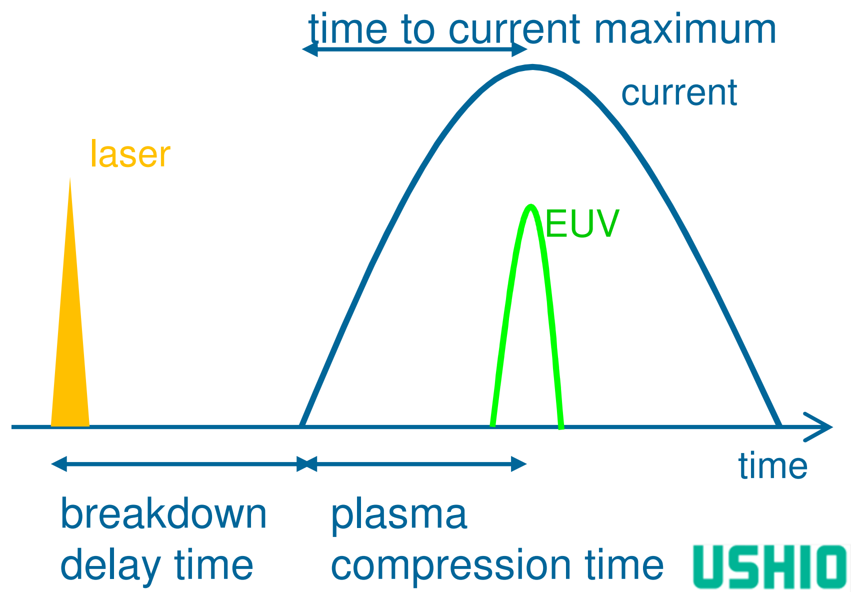
Timing = EUV Efficiency

- Breakdown delay time ∝
  - Expansion of the plasma
- Time to current maximum ∝
  - Inductance L (= mechanical design of Source Head)
  - Capacitance C (capacitor banks)
- Plasma compression time ∝
  - Force F (= magnetic pressure, i.e. current)
  - Inertia I (= mass of Tin atoms)
  - Distance D (= spatial distribution of Tin atoms at breakdown)
  - I & D are determined by the laser

NOK

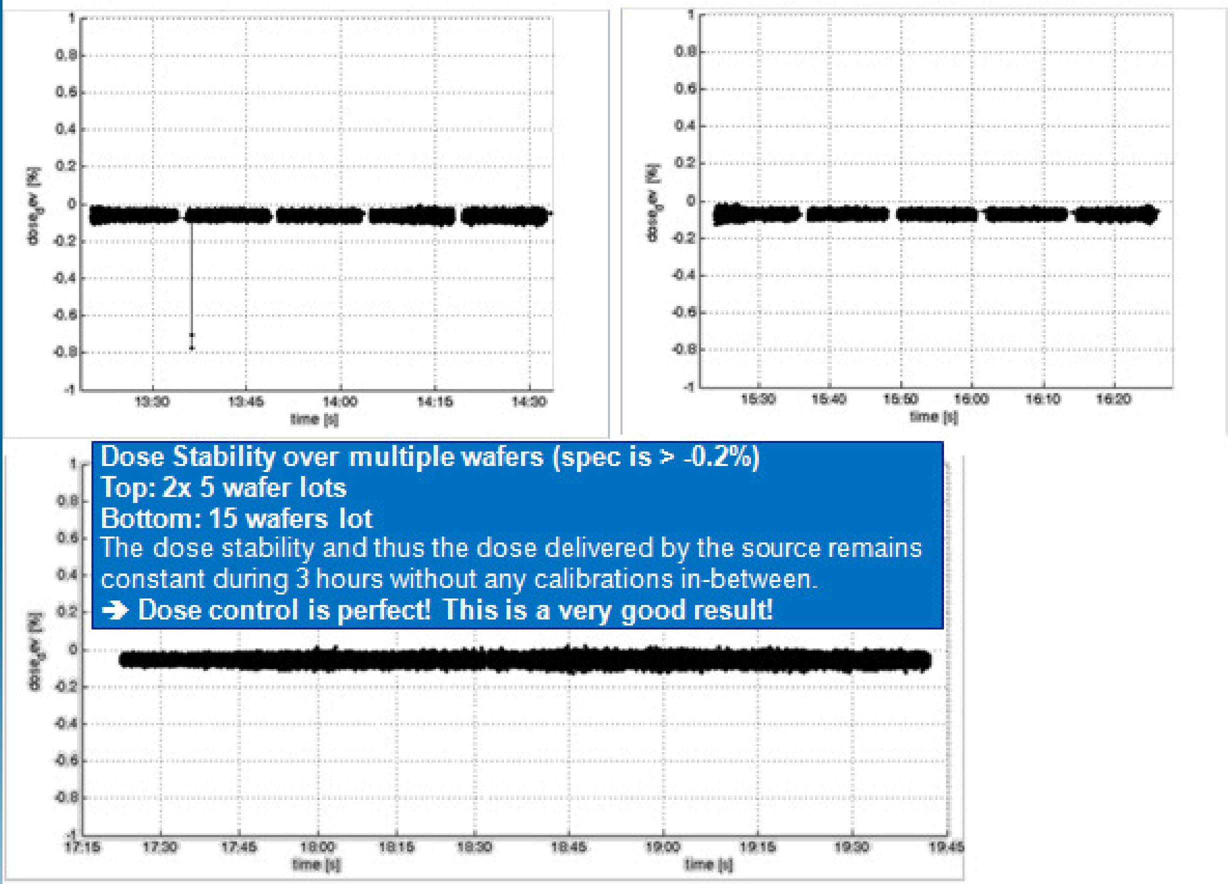


OK = at timing of pinch
all dissipated power → EUV power



Dose Stability Means CD Uniformity

- Dose stability is 3 σ < 0.1 % [Spec. 3 σ < 0.2%]



Dose Stability over multiple wafers (spec is > -0.2%)
Top: 2x 5 wafer lots
Bottom: 15 wafers lot
The dose stability and thus the dose delivered by the source remains constant during 3 hours without any calibrations in-between.
➔ Dose control is perfect! This is a very good result!

Conditions:

IMEC's NXE:3100

0.25NA/ 0.81s

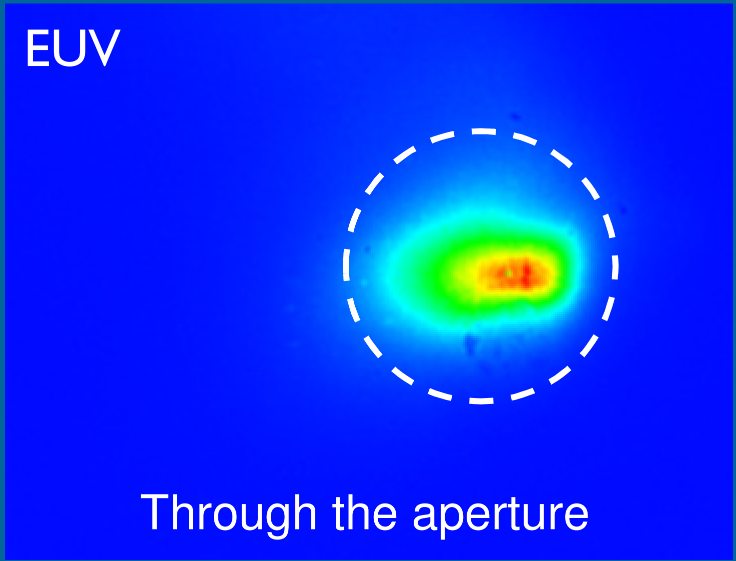
14.5mJ/cm2

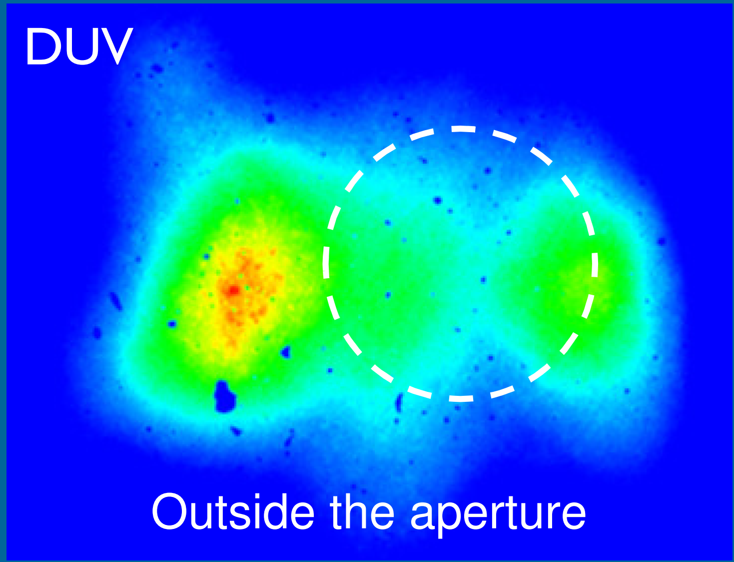
27nm LS

Exposure time was 1hr. 11min. for 5-wafer lot full field, full wafer coverage

Exposure time 3hr. 10min. for 15-wafer lot full field, full wafer coverage

OOB DUV – LDP Photons Are Clean





- LDP IF aperture spatially filters out DUV radiations
- DUV is imaged outside the IF aperture and is thus mechanically blocked
- Mostly, only EUV photons go through the IF aperture

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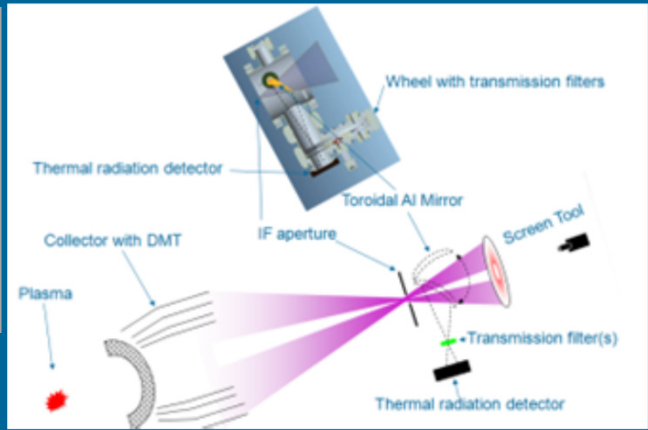
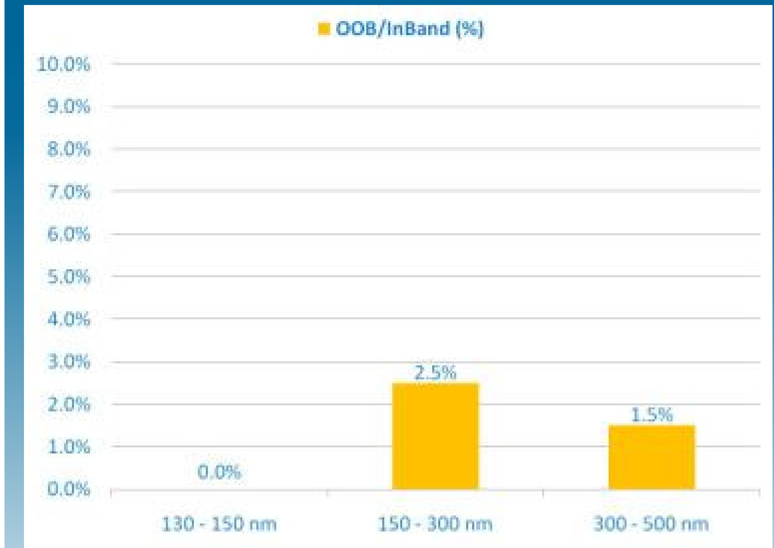
OOB DUV – LDP Photons Are Clean

LDP - NXE:3100	OOB/InBand (%)
130 - 150 nm	0.0%
150 - 300 nm	2.5%
300 - 500 nm	1.5%





Measurements:

Output inband EUV power: 5 W

Filters:

CaF2	130 – 12000 nm
Suprasil 300	150 – 4000 nm
WG295	300 – 2800 nm
GG495	500 – 2800 nm
Suprasil 300 + Si	1500 – 4000 nm
WG295 + Si	1500 – 2800 nm

LDP photons are clean

No need for SPF

No impact upon wafers

Proven @ ADT

Now being validated @ IMEC

OOB IR – LDP Photons Are Clean

- NXE:3100 with LDP technology does not require a Spectral Purity Filter (SPF)

LDP photons are clean

No SPF

No loss of In-Band EUV power

Lower kJoule/Wafer

More wafers/year

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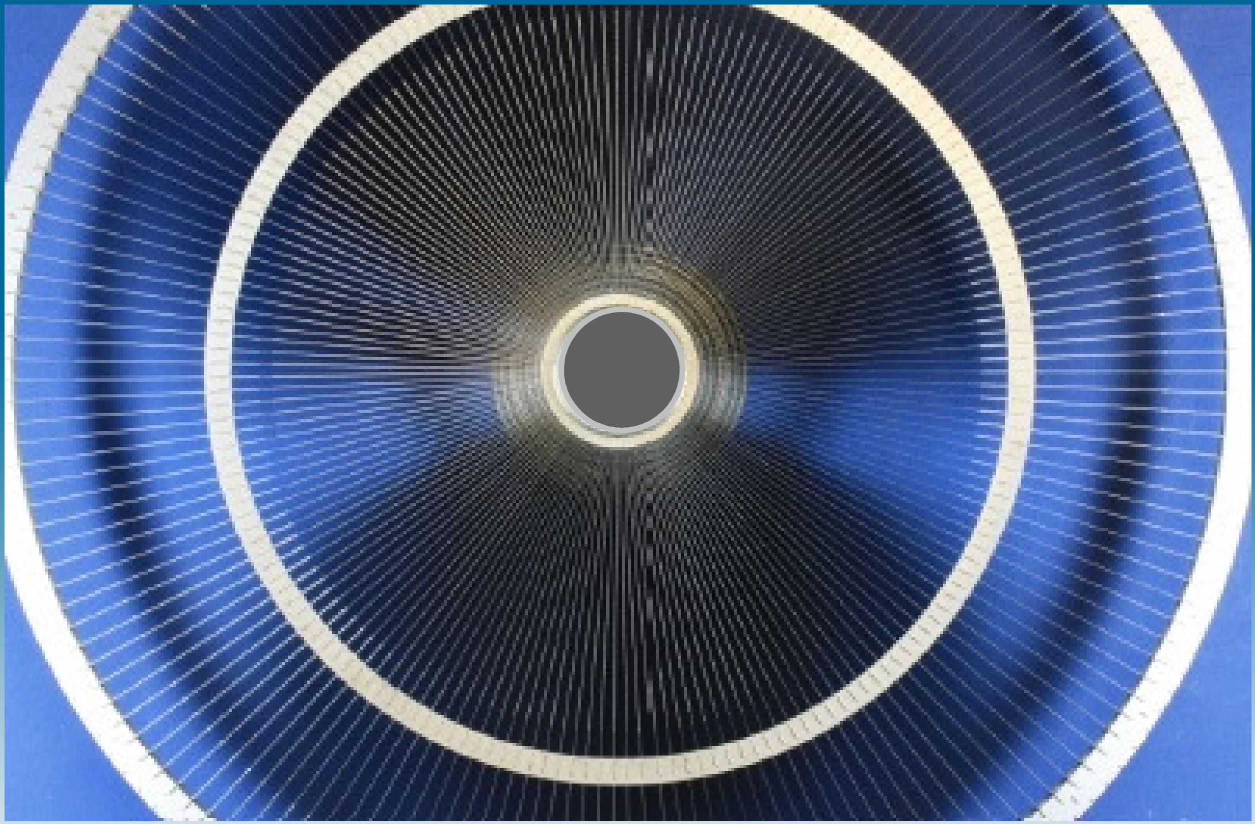
Debris & Contamination Management

- XTREME's unique Foil Trap module is designed:
  - To protect the collector mirror from Tin deposition and erosion (debris)
  - To prevent Tin transport towards the scanner and the pellicle-less mask
    - Tin contaminants on mask → Yield loss



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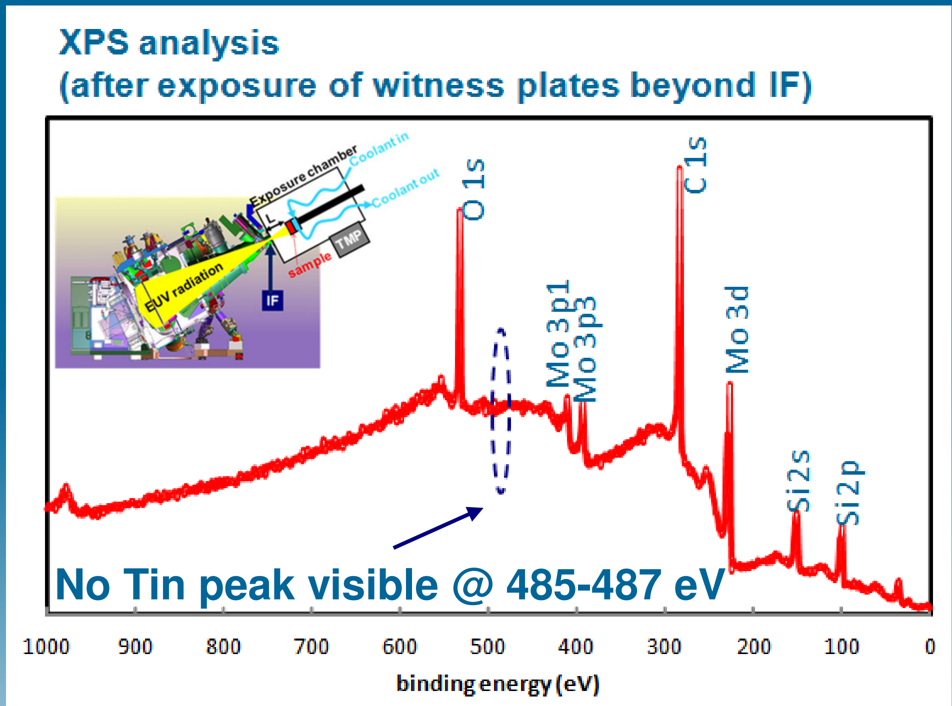
No Tin Contaminant Beyond IF

- Mechanical baffles and Foil Trap prevent Tin contaminants to transport - through the IF aperture - towards the scanner and the pellicle-less mask



The "dirty" area physically isolated

No Tin transport

No scanner contamination

No Tin printing defects

No yield loss

Confirmed by ASML: over 1 year of utilization w/ ADT

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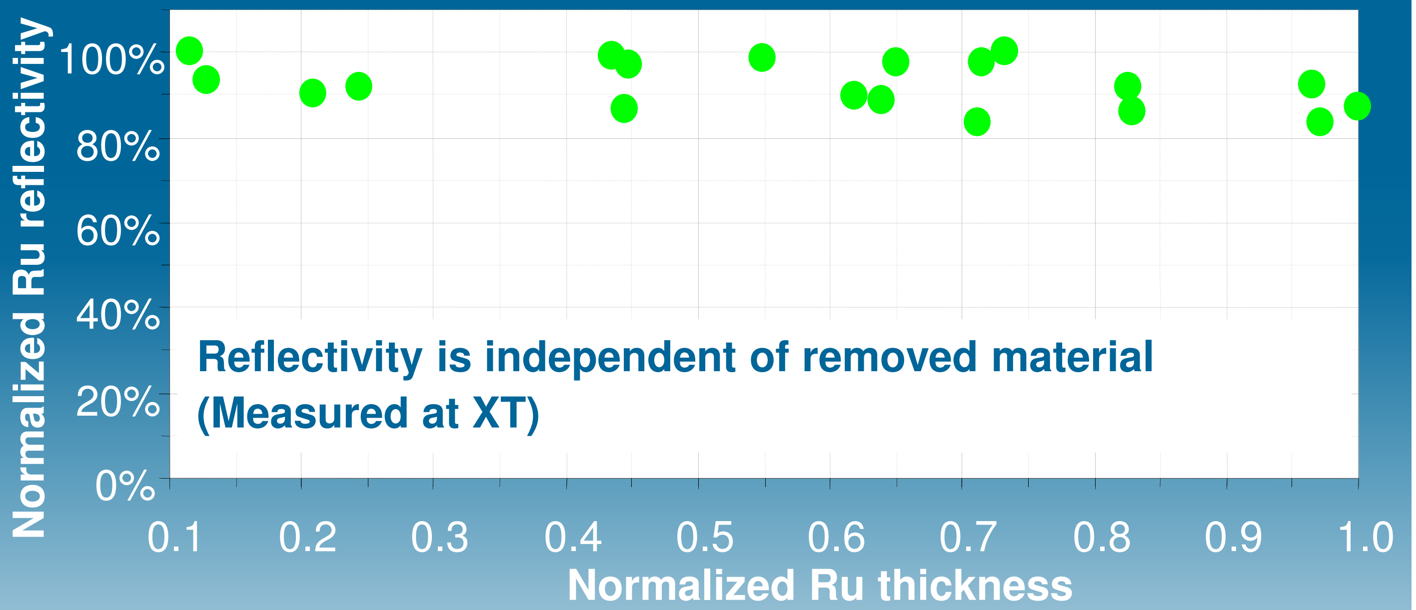
Long Collector Mirror Lifetime Is Proven

- The FT protects the collector mirror
- Ruthenium (Ru) coating can also be used as sacrificial material with constant optical performance of the collector

LDP collector lifetime ~ 1 year



* Confirmed by ASML: over 1 year of utilization w/ ADT

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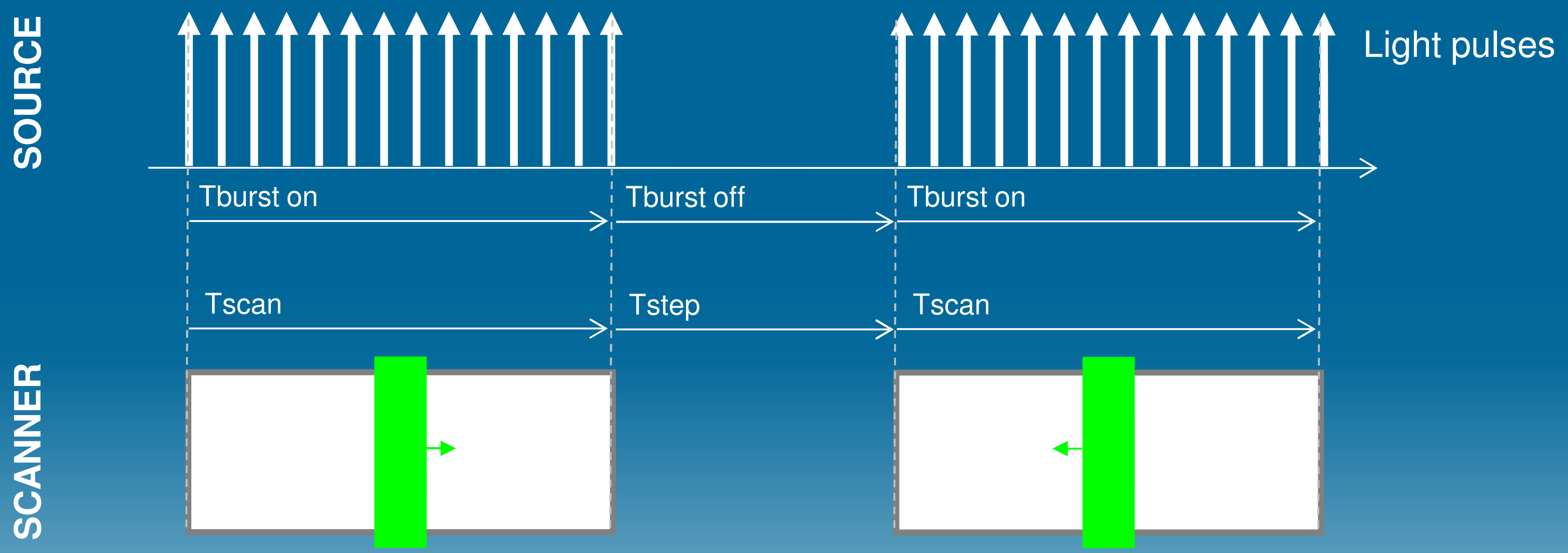
High Duty Cycle Means Throughput

- High Source Duty Cycle = Source is ready when the scanner needs light
  - High Source Duty Cycle ⇔ Source Duty Cycle (Supply) > Process Duty Cycle (Demand)

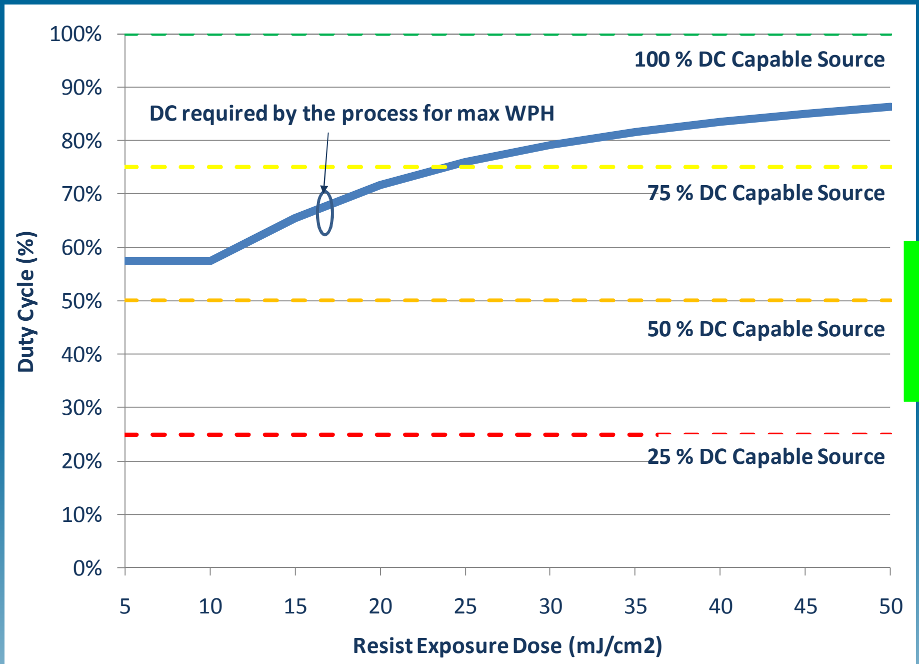


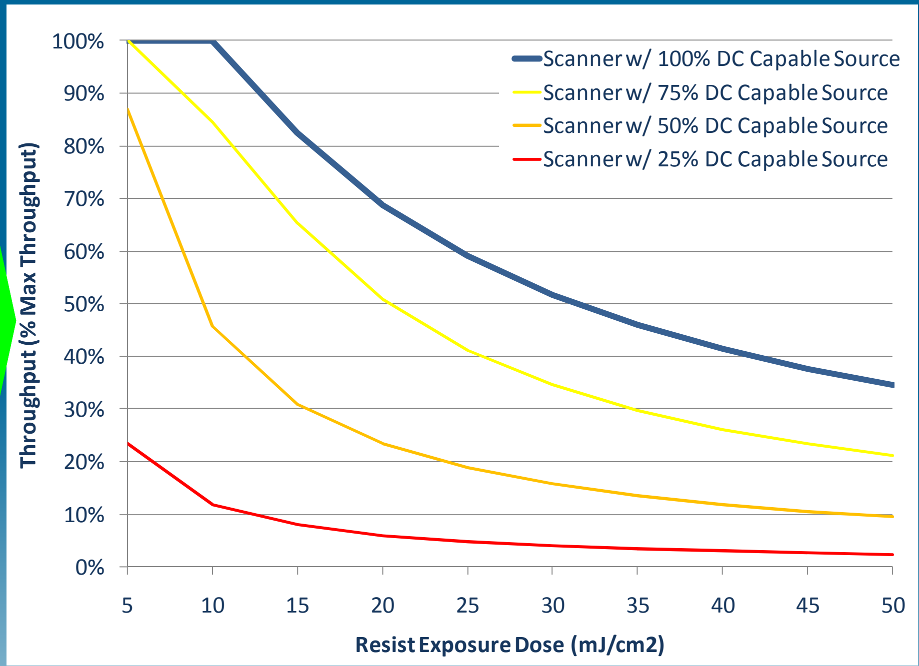
Source Duty Cycle (%) = T burst on / (T burst on + T burst off)

Process Duty Cycle (%)= T scan / (T scan + T step)

High Duty Cycle Means Productivity

- High Source Duty Cycle is required to enable maximal throughput
  - Low source Duty Cycle = Scanner waits for the Source = Low throughput





Where Are We Now ?

Where Are We Today

7 W
50% Duty Cycle

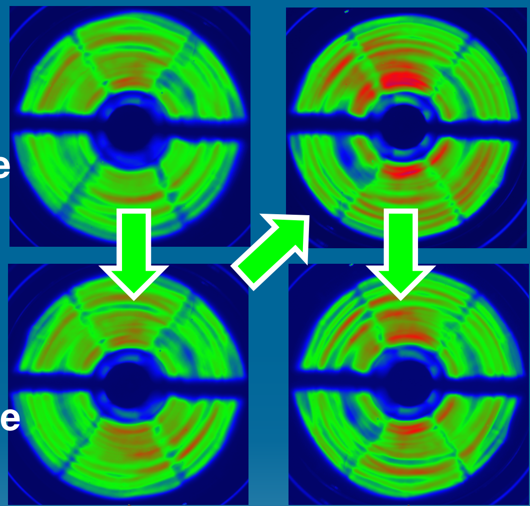
7 W
100 % Duty Cycle

15 W
50% Duty Cycle

15 W
100 % Duty Cycle

33 W
50 % Duty Cycle

20 W
100 % Duty Cycle



37 W
50 % Duty Cycle

30 W
100 % Duty Cycle

2010			2011												2012		
Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.

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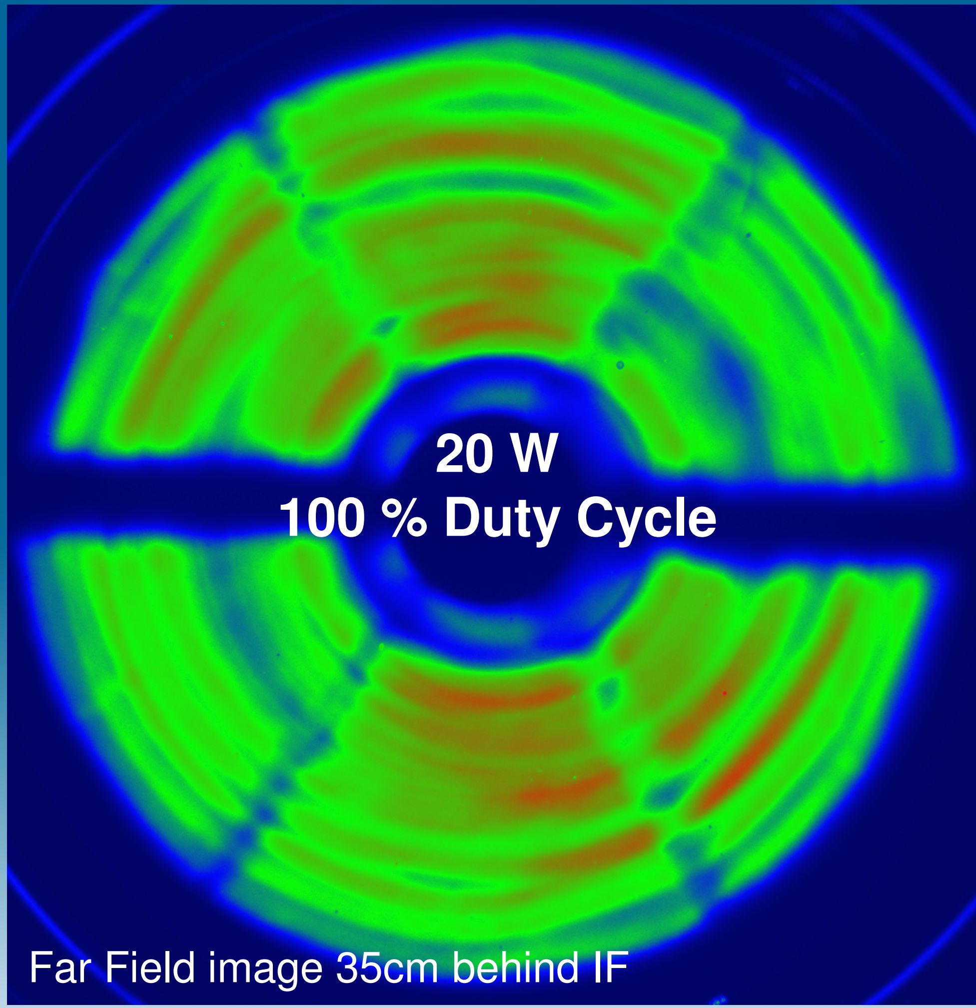
The Initial Breakthrough

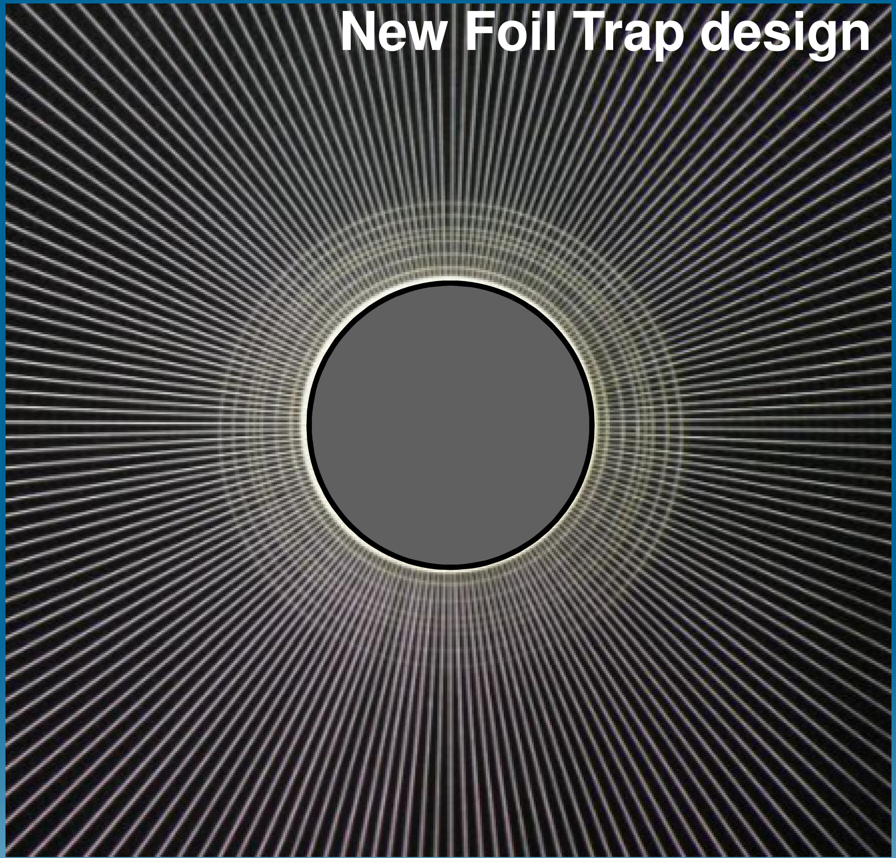


Removing The Bottleneck – Design For Manufacturing

- Bended blades
- Irregular spacing

→Low optical transmission < 60%

→Higher heat load



- Straight blades
- Regular spacing

→High optical transmission > 76%

→Reproduced on 5 newly manufactured FTs

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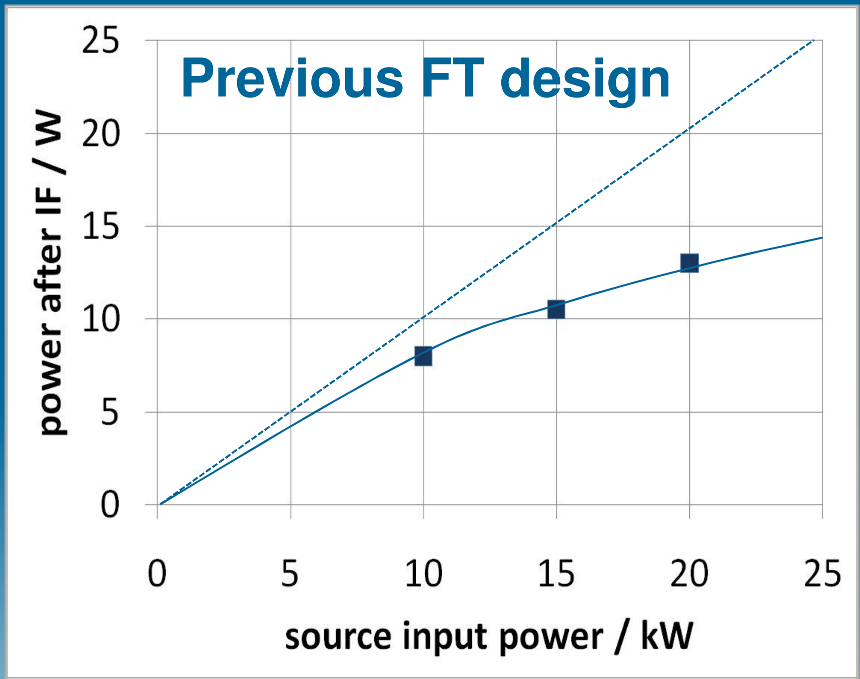
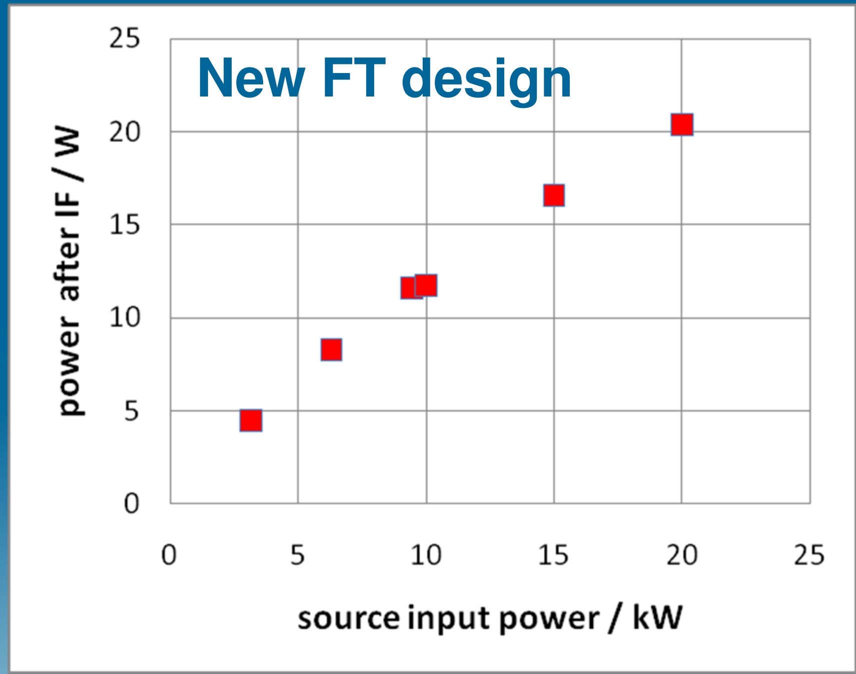
The Initial Breakthrough

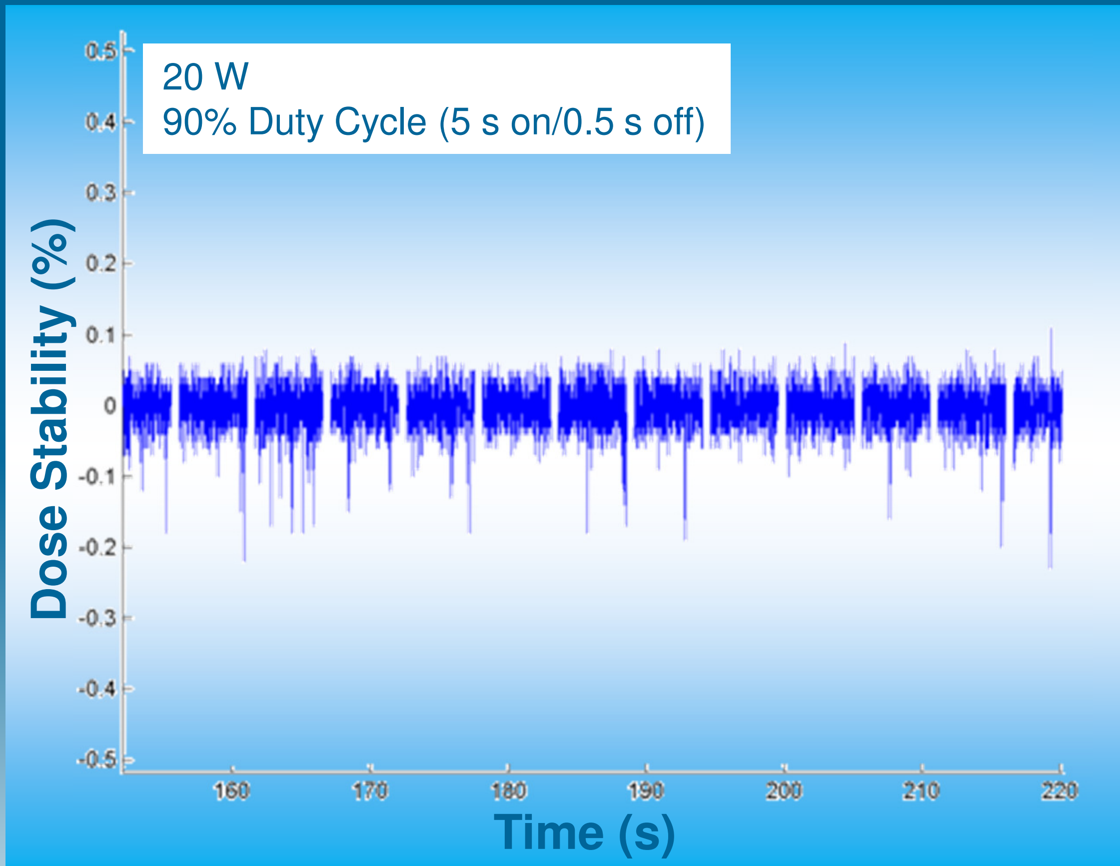
- New Foil Trap design → output power now scales linearly





Dose Stability Is Also Within Specifications

- NXE:3100 Specification: $3\,\sigma \leq \pm 0.2\ \%$



Automated feedback implemented since ADT

Continuous Tin delivery ensures timing stability

LDP dose control independent of the power level

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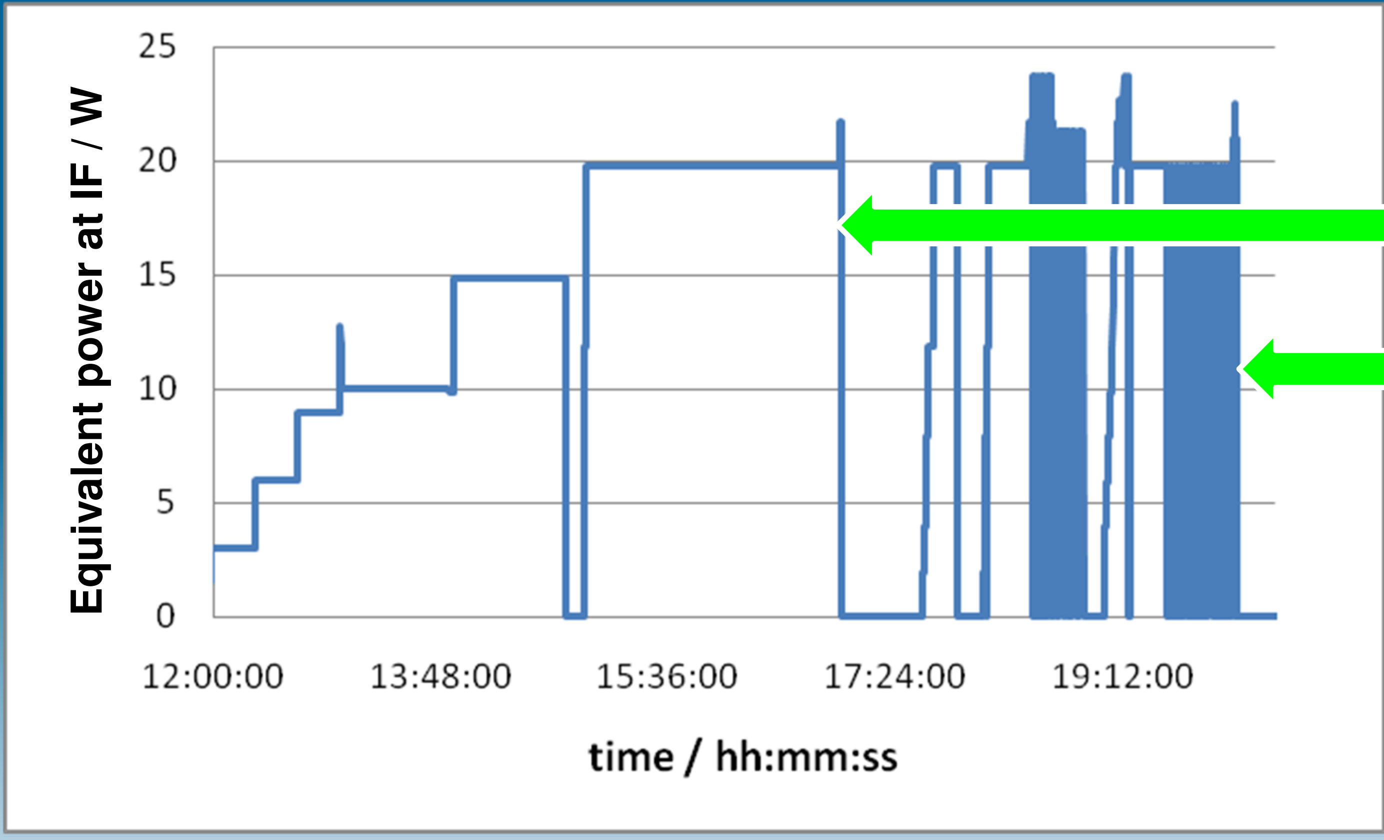
The Breakthrough Is Sustainable

- Cumulative 9 hours @ 20W over 3 days proven



20 W output power
20 kW input power
100 % DC

20 W output power
20 kW input power
Variable DC
(to simulate scanner actual operations)

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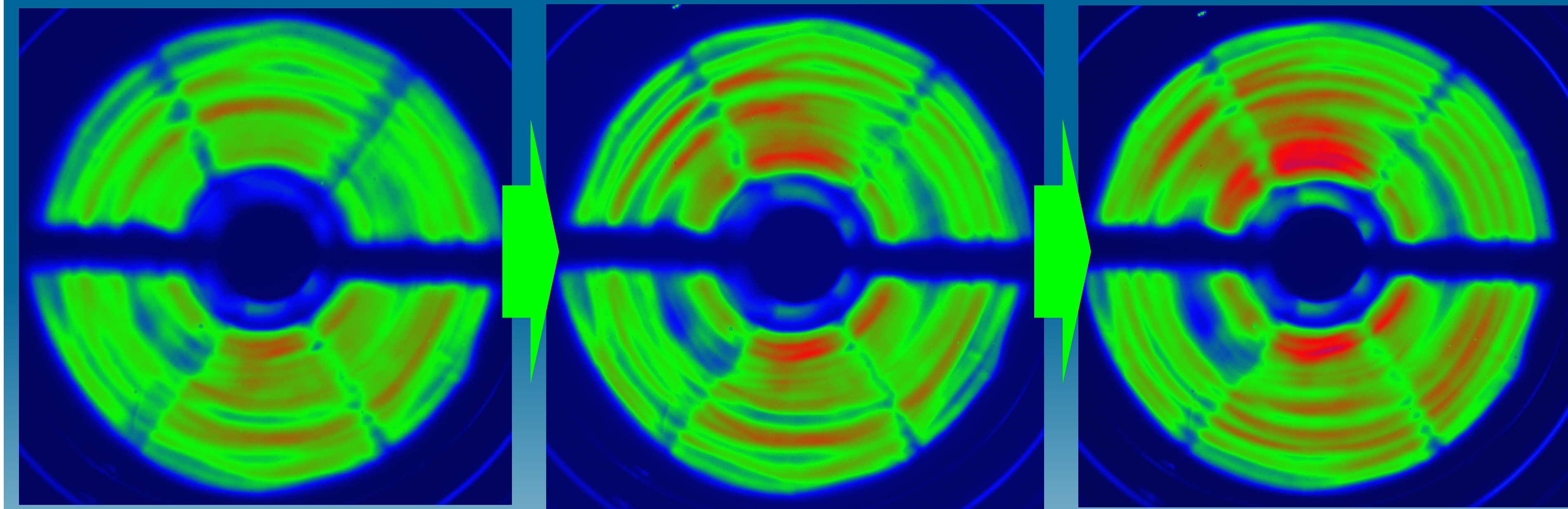
Since Then, Progress Is Steady

33 W
50 % Duty Cycle

30 W
100 % Duty Cycle

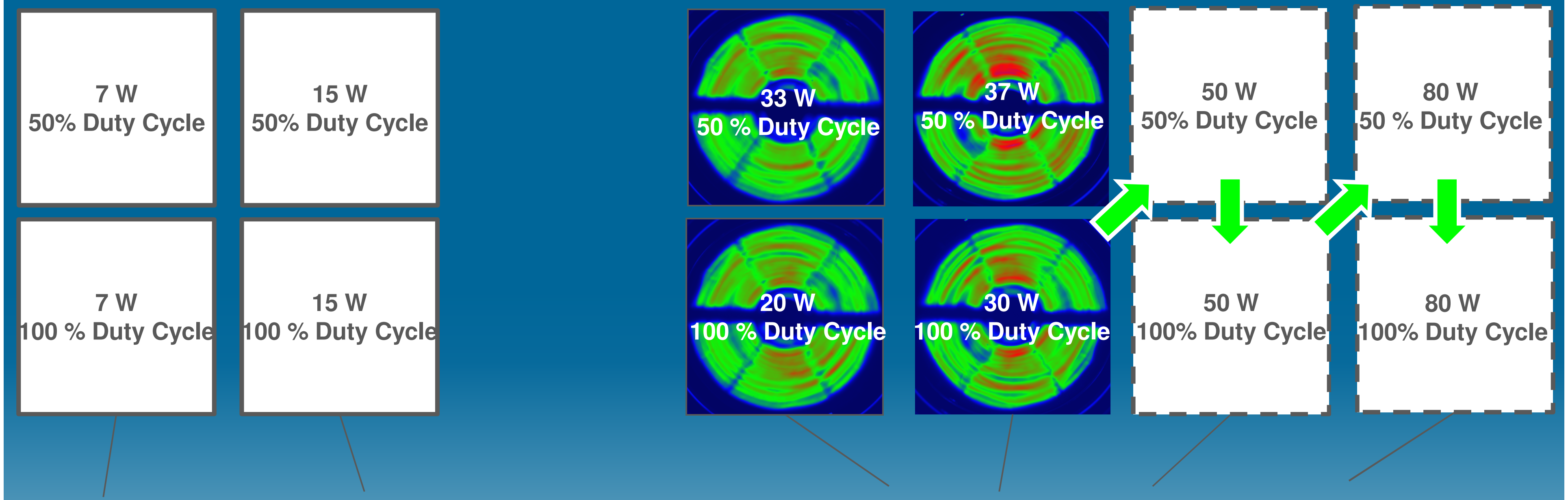
37 W
50% Duty Cycle



Far Field images 35cm behind IF

What’s Next ?

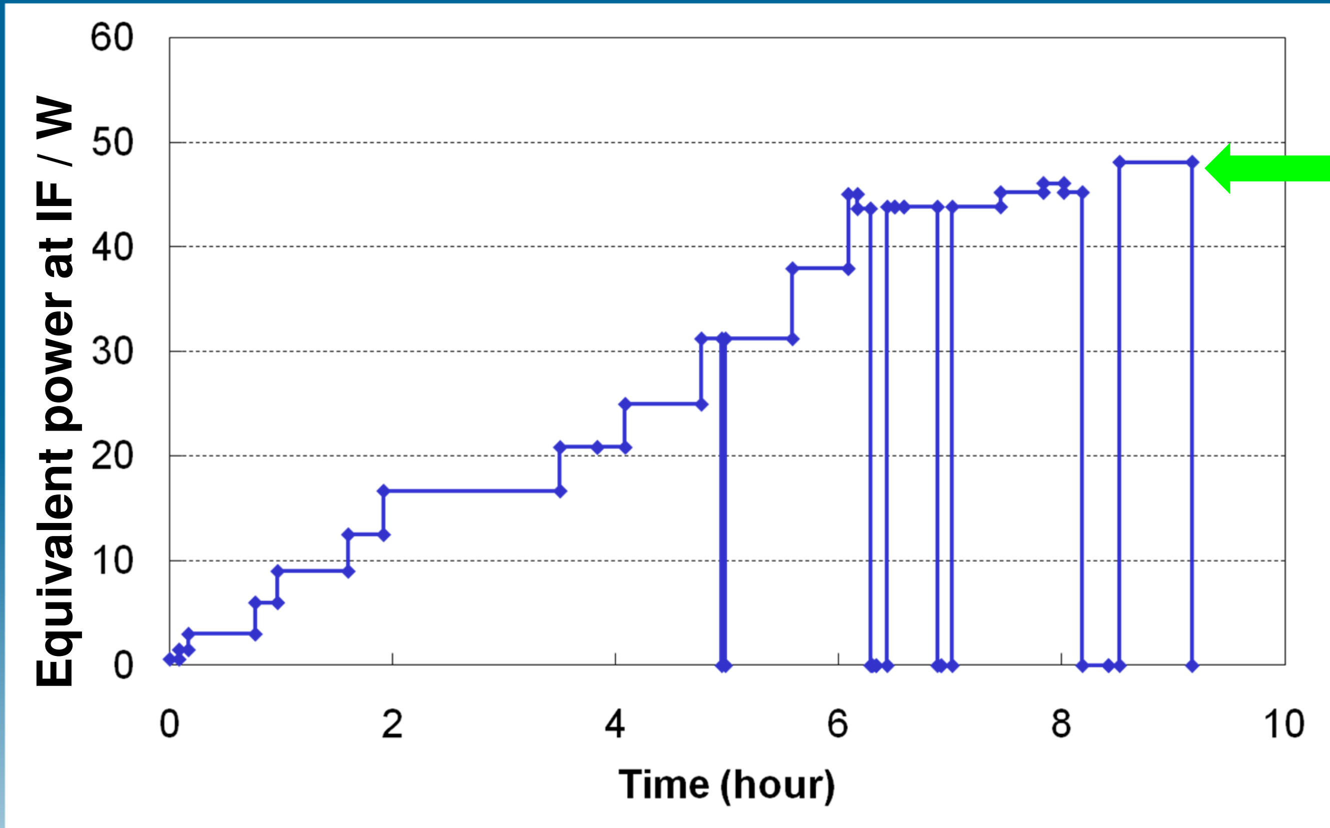
Higher Power Is Around The Corner



2010			2011												2012		
Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.

48 kW Source Head Will Soon Deliver 50 W

- Next generation Source Heads are now tested as stand alone module



48 W output power
48 kW input power
100% DC
40 minutes

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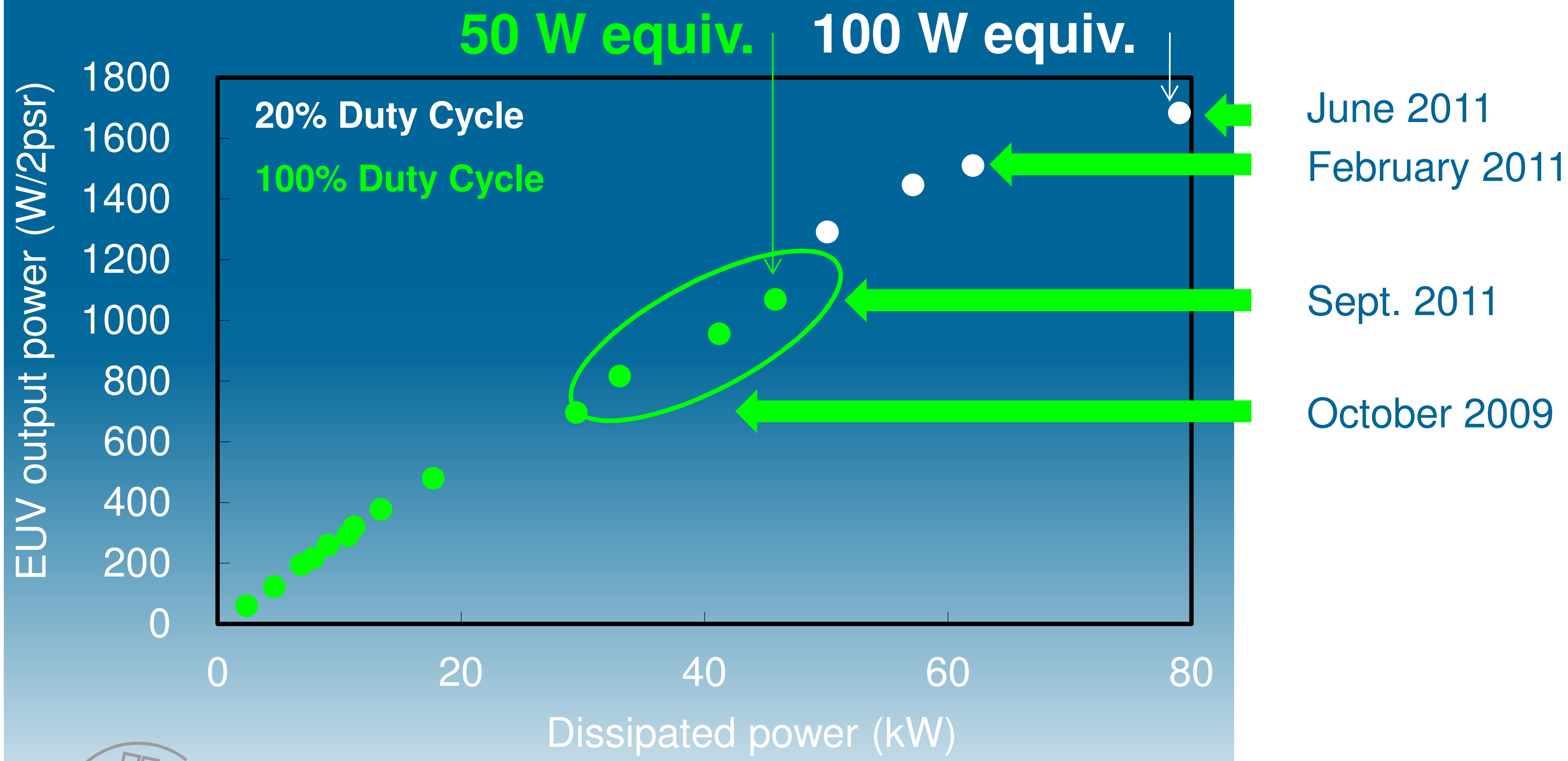
Equiv. 50W Proven At Module Level

- 76 kW Source Head will be used to generate 100 W EUV output power
  - 1700 W/2psr / 76kW → ~ 2.3% CE



Towards HVM

- The path towards HVM high power is clear

250 W Source

48 kW Source Head → 300 kW Source Head

Increase electrical input power by increasing repetition rate

Increase the rotation speed of Source Head wheel

Increase Tin cooling capacity

50 W Foil Trap → 250 W Foil Trap

Increase distance to plasma

Increase cooling efficiency

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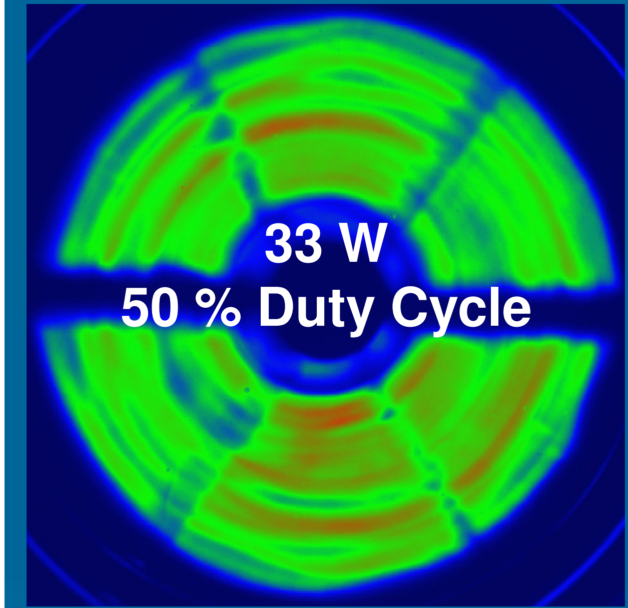
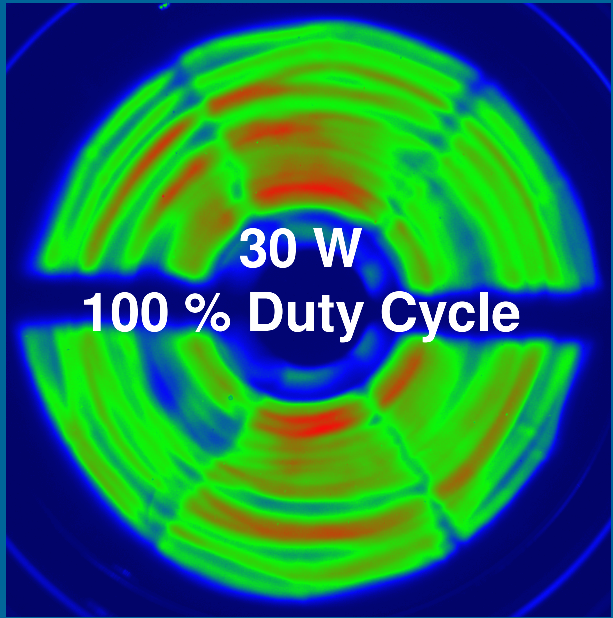
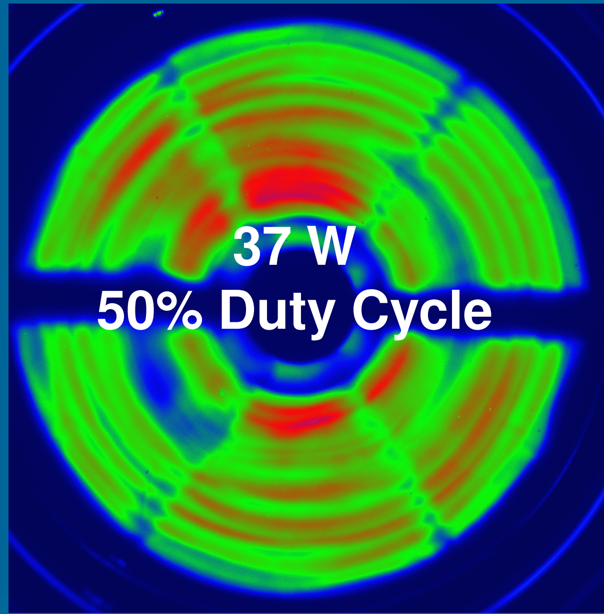
Conclusions







- 30 W / 100% DC has been achieved at system level
- 37 W / 50 % DC has been achieved at system level
- 50 W / 100% DC has been achieved at the module level (SH)
- Higher power is around the corner
- LDP is scalable to higher power. The path to 250 W is identified

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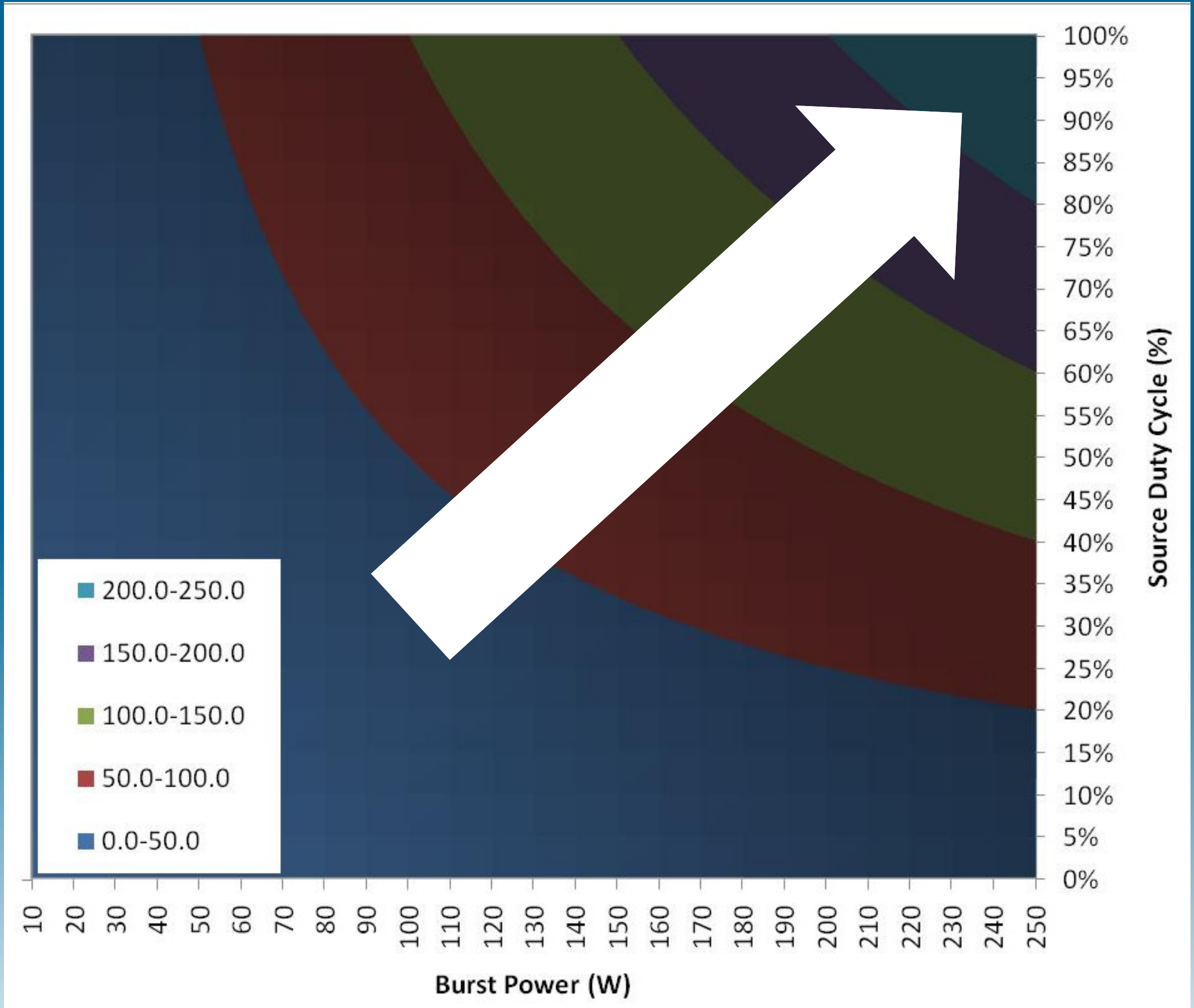
THANK YOU VERY MUCH FOR YOUR ATTENTION

XTREME technologies GmbH
www.xtremetec.de

Why LDP – The Rationale

High Duty Cycle Means Useful Power

- Useful Power = Burst Power x Duty Cycle



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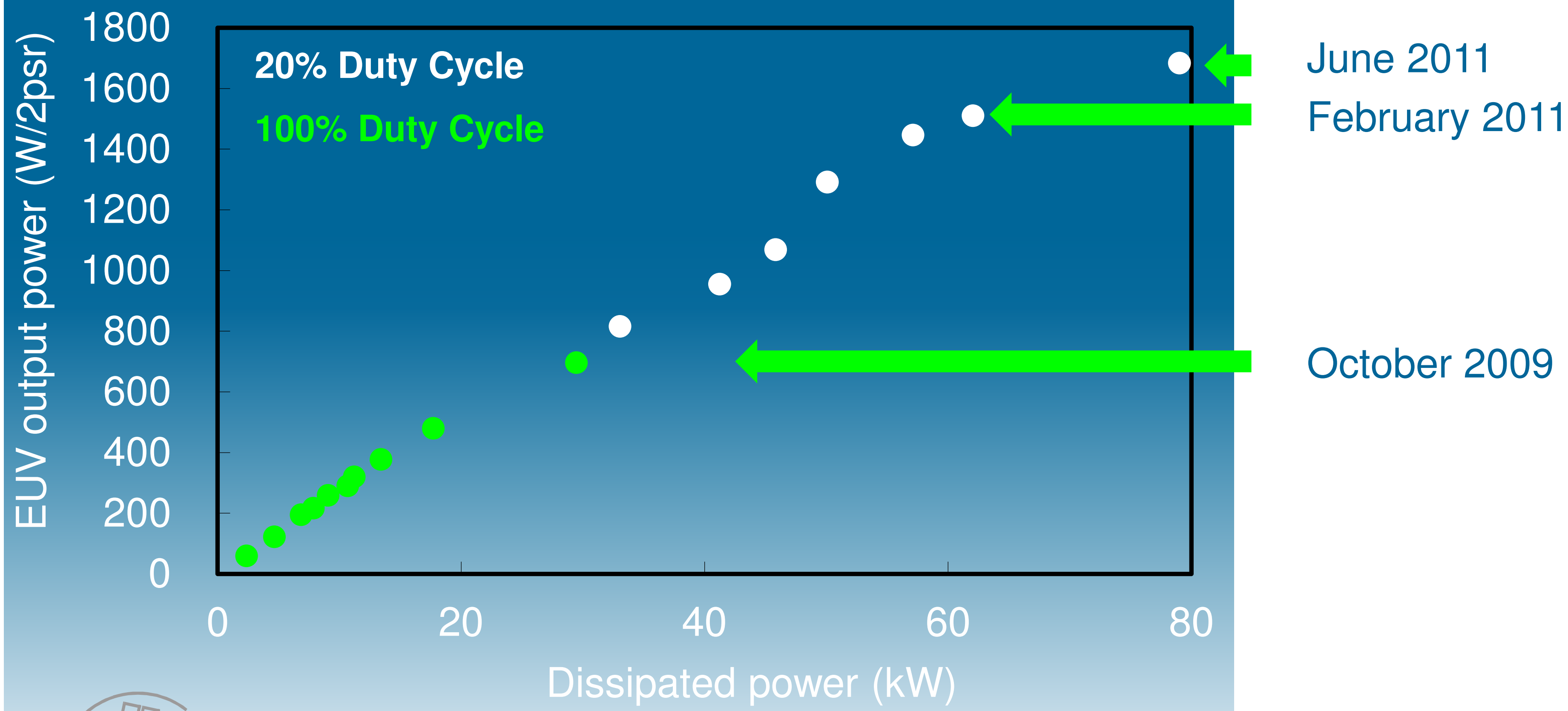
Higher Power Is Around The Corner

- To achieve 100 W EUV power, higher input power Source Heads is required
  - The 100W enabling 76 kW Source Head is being tested



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